

## IRAS Observations of Starburst Galaxies

Kazuhiro Sekiguchi

Department of Astronomy, New Mexico State University  
Las Cruces, New Mexico 88003 U.S.A.ABSTRACT

Far-infrared properties of Starburst galaxies were analyzed using IRAS observations at 25, 60, and 100  $\mu\text{m}$ . Seventy-nine of 102 Starburst galaxies from the list of Balzano were detected. These galaxies have high IR luminosities of up to a few  $10^{12} L_{\odot}$  and concentrate in a small area of the IR color - color diagram. The IR power law spectral indices,  $\alpha$ , lie within the ranges  $-2.5 < \alpha(60,25) < -1.5$  and  $-1.5 < \alpha(100,60) < 0$ . These observed indices can be interpreted in terms of a cold ( $\sim 30$  K) disk component and a warm ( $\sim 80$ -90K) component. More than 80% of the 60  $\mu\text{m}$  emission comes from the warm component. The fraction of the 60  $\mu\text{m}$  emission attributable to the warm component can be used as an activity indicator.

INTRODUCTION

Strong infrared excess is known to be a property of starburst galaxies. It has been suggested (Rieke and Low 1975; Rieke et al. 1980; Weedman et al. 1981; Gehrz, Sramek, and Weedman 1983) that this IR excess is from gas and dust heated by newly born massive stars. The maxima of these IR fluxes fall into the IRAS wavelengths ranges, 12, 25, 60, and 100  $\mu\text{m}$ . There is an indication that a large fraction of the IRAS selected infrared luminous galaxies are starburst galaxies (Elston et al. 1985; Allen, Roche, and Norris 1985; Soifer et al. 1986). Some of them such as NGC 6240 (Wright, Joseph, and Meikle 1984) show high luminosities, up to  $10^{12} L_{\odot}$ , comparable to those of quasars.

It is therefore of interest to examine the far-infrared properties of starburst galaxies. In this paper we present the infrared properties of starburst galaxies based on the IRAS survey data. Then we try to interpret these properties in terms of their star formation activity.

SAMPLE SELECTION

Galaxies studied by Balzano (1983) were used as the prime sample of starburst galaxies. These galaxies are known to have a nuclear starburst which dominates their observable properties in many wavelengths. In addition to the Balzano galaxies, two well known starburst galaxies NGC 3690 (Gehrz, Sramek, and Weedman 1983) and NGC 6240 (Rieke et al. 1985) were included in the sample. Eighty-one of 104 sample starburst galaxies are identified and listed in the Cataloged Galaxies and Quasars Observed in the IRAS Survey (Lonsdale et al. 1985). Quoted flux densities of 25, 60, and 100  $\mu\text{m}$  in the catalogue were used. Since color correction for a black body source with  $T \sim 100$  K is small at 60 and 100  $\mu\text{m}$  ( $< 4\%$ ), and  $\sim 16\%$  at 25  $\mu\text{m}$ , no color corrections were applied.

## RESULTS

Figure 1 is a plot of power law spectral index  $\alpha(60,25)$  vs.  $\alpha(100,60)$  for all the starburst galaxies observed by the IRAS survey. The spectral index is defined by  $-\alpha(\lambda_2, \lambda_1) = \text{Log}(f_2/f_1)/\text{Log}(\lambda_2/\lambda_1)$ , where  $f_i$  is the observed flux density at  $\lambda_i$ . This figure shows a large scatter of observed colors among the objects. Some are even located above the power law line. No apparent trend or tendency is seen from this plot. One reason for this large scatter is that not all of the observed flux values are of the same quality. (A detailed discussion of the uncertainties of IRAS measurements is given in IRAS Explanatory Supplement. Beichman et al. 1985)

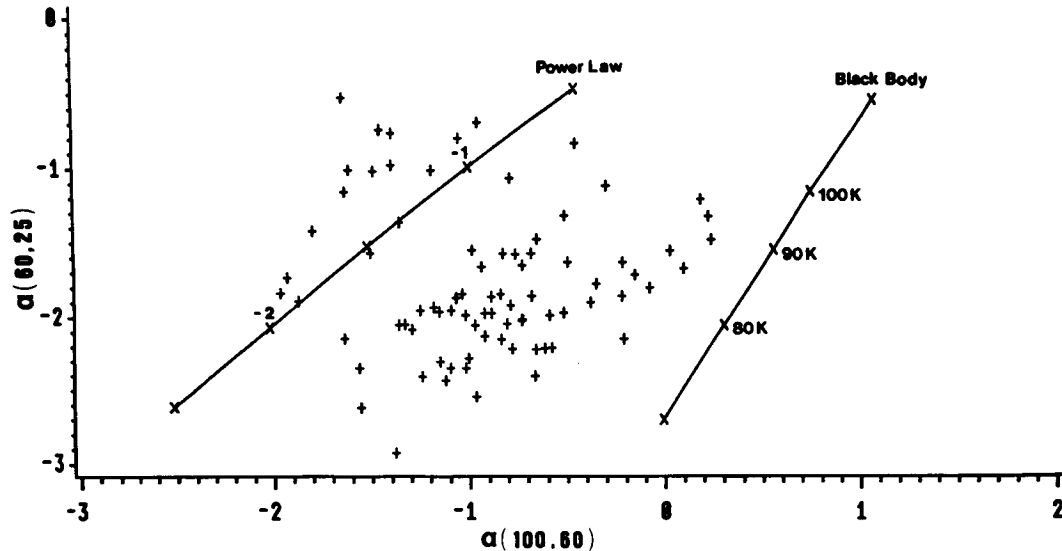


Figure 1. An infrared color-color plot for all starburst galaxies detected and identified by the IRAS survey. The spectral indexes are defined in the text. The loci for Black body and Power law sources have been plotted for comparison. The numbers along the Power law line are the spectral indices and along the Black body line are the temperatures.

To obtain more reliable far-infrared colors of the starburst galaxies, we imposed certain constraints on the sample. First, only flux densities of good quality were selected. Then, to reduce uncertainties, only quoted flux values with a 1 $\sigma$  flux uncertainty  $\delta f_\nu/f_\nu < 0.12$  were used. Finally, to minimize possible effects of the different diaphragm sizes at 25  $\mu\text{m}$  ( $\sim 0'.76 \times 4'.6$ ), 60  $\mu\text{m}$  ( $\sim 1'.5 \times 4'.75$ ), and 100  $\mu\text{m}$  ( $\sim 3'.0 \times 5'.0$ ), a distance limit  $z > .0067$  corresponding to distances exceeding 28 Mpc (A Hubble constant of 75  $\text{km s}^{-1} \text{Mpc}^{-1}$  is used throughout this paper) was applied. If a typical galactic disk has a radius 20 kpc, then a distance of 23 Mpc implies 3'.0 in angular dimension. Therefore, at least for the flux densities at 60 and 100  $\mu\text{m}$  used to obtain total infrared luminosity, the diaphragm size effect should be small.

After having applied these criteria, nineteen objects remained for further analysis. Table I gives the identifications of these galaxies along with other pertinent information. Figure 2 shows the infrared color of these 19 galaxies. From this figure it is apparent that starburst galaxies occupy a distinct and quite localized position in the diagram. The mean spectral indices for these galaxies are  $\langle \alpha(60,25) \rangle = -2.02 \pm 0.16$  and  $\langle \alpha(100,60) \rangle = -0.71 \pm 0.35$ .

Table I

Object	IRAS Name	$\alpha(60,25)$	$\alpha(100,60)$	$z^1$	$T_w$ ( $^{\circ}$ K)	P	Log(Lw) (ergs s $^{-1}$ )	Log(Lc) (ergs s $^{-1}$ )	Log(LIR) (ergs s $^{-1}$ )
Mk 133	09578+ 7222	-1.97	-1.15	0.0068	87	.82	43.43	42.93	43.55
Mk 158	10560+ 6147	-2.22	-0.66	0.0068	80	.89	43.85	43.14	43.93
Mk 161	10591+ 4529	-2.13	-0.92	0.0200	82	.85	44.25	43.68	44.36
Mk 201	12116+ 5448	-1.87	-0.22	0.0084	85	.93	44.52	43.54	44.56
Mk 213	12290+ 5814	-1.99	-1.02	0.0105	86	.84	43.92	43.36	44.02
Mk 286	14188+ 7148	-2.02	-0.73	0.0250	84	.87	44.72	44.06	44.81
Mk 326	23256+ 2315	-1.85	-0.84	0.0130	88	.86	44.12	43.48	44.21
Mk 496E	16104+ 5235	-1.93	-0.78	0.0290	86	.86	45.02	44.39	45.11
Mk 602	02572+ 0234	-1.87	-0.89	0.0099	88	.85	43.84	43.23	43.94
Mk 691	15447+ 1802	-2.30	-1.15	0.0110	80	.83	43.93	43.45	44.06
Mk 708	09395+ 0454	-2.22	-0.78	0.0070	80	.87	43.67	43.04	43.76
Mk 717	10078+ 2439	-1.73	-0.16	0.0212	88	.93	44.56	43.57	44.60
Mk 799	13591+ 5934	-2.09	-1.29	0.0110	85	.81	44.36	43.91	44.50
Mk 897	21052+ 0340	-2.05	-0.80	0.0260	83	.87	44.60	43.95	44.68
Mk 1089	04591 - 0419	-1.99	-0.59	0.0120	83	.89	44.04	43.31	44.12
Mk 1093	05053 - 0805	-2.21	-0.58	0.0140	80	.90	44.52	43.76	44.59
Mk 1379	14150 - 0711	-2.03	-0.73	0.0094	83	.87	43.90	43.24	43.98
NGC3690	11257+ 5850	-1.81	-0.08	0.0100	86	.94	45.35	44.29	45.38
NGC6240	16504+ 0228	-2.15	-0.21	0.0246	80	.94	45.43	44.43	45.47

1. Redshift Sources: Balzano (1983), for NGC 3690 Sandage and Tammann (1981) and for NGC 6240 Fosbury and Wall (1979).

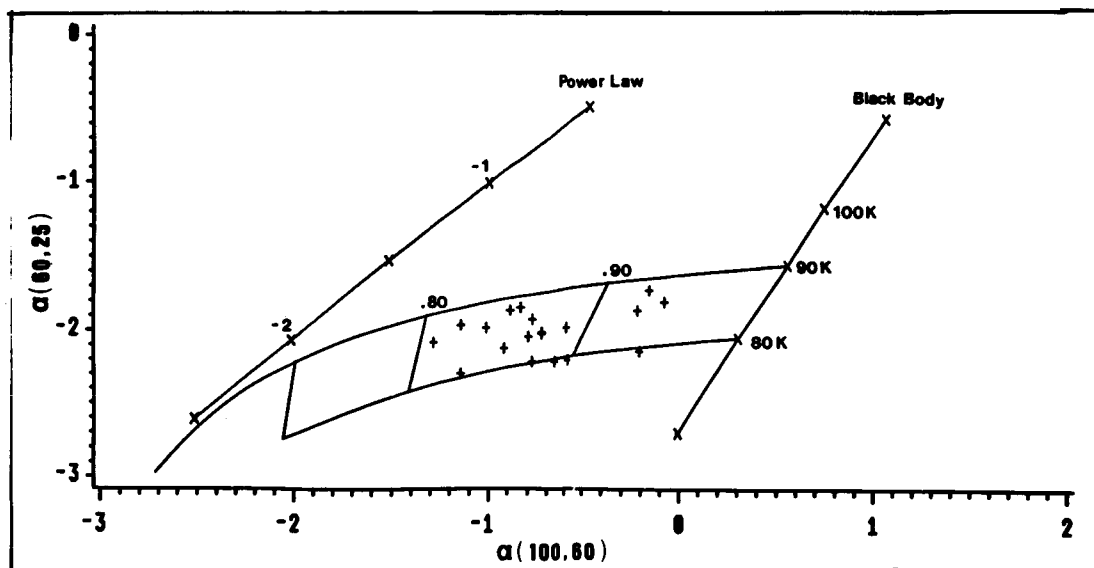


Figure 2. An infrared color-color plot for starburst galaxies with high quality measurement, 1 $\sigma$  flux uncertainty  $\delta f_v/f_v < 0.12$ , and redshift  $z > .0067$ . The loci for the two black-body model have been plotted in addition to the Black body and the Power law lines. Numbers along the two black-body model lines are the fraction of the warm component contribution to the total 60  $\mu$ m flux.

To interpret the far-infrared colors of these galaxies, a two component black body model was used. A fixed cool temperature,  $T_c$ , of 30 K which represents the cold disk component was assigned. Then, a unique warm temperature,  $T_w$ , which represents all the IR sources except the 30 K component, can be obtained from the observed colors. In figure 2, we plotted loci of the two temperature model. Numbers along the two temperature model curves are the fractions,  $P$ , of the  $60\ \mu\text{m}$  warm component flux to the total  $60\ \mu\text{m}$  flux observed. The galaxies'  $T_w$  and  $P$  determined from observed colors are given in Table I.

Finally, using the procedure outlined by Lonsdale et al. (1985), the total IR luminosities from the two temperature model were computed. The total IR,  $L_{\text{IR}}$ , the warm,  $L_w$ , and the cool,  $L_c$ , component luminosities are given in Table I.

## DISCUSSION

The far-infrared colors of the starburst galaxies are quite distinct. Their color indices  $\alpha(60,25)$  are steeper than the range of Seyfert selection criterion,  $-1.5 < \alpha(60,25) < -0.25$  (de Grijp et al. 1985). Compared to the median color indices of Seyferts and H II region galaxies (Miley, Neugebauer, and Soifer 1985), separation from Seyfert 1's is clear. However, there is significant overlap with Seyfert 2's. As is expected, H II region galaxies show almost the same color as those of the starbursts. On the other hand, the indices  $\alpha(100,60)$  of the starbursts are similar to those of the Seyfert's. They are much flatter than those of non-active spirals (de Jong et al. 1984) and infrared galaxies in the IRAS minisurvey (Soifer et al. 1984).

From Figure 2, it can be seen that the starburst galaxies occupy a relatively small range,  $\sim 80$  to  $90$  K, of  $T_w$  and a wider range,  $\sim .80$  to  $.95$  of  $P$ . Since the warm component mainly represents warm gas and dust associated with a star-formation region,  $T_w$  and  $P$  should indicate their physical state and degree of activity. The flat  $\alpha(100,60)$  of starburst galaxies may be the result of a larger warm component contribution to the total IR flux than that of non-active spirals (ie. large  $P$ ).

The total IR luminosity of the starburst galaxies ranges from  $10^{10}$  to  $10^{12}$   $L_\odot$ . NGC 6240 is the most extreme. At the low luminosity end there is overlap with non-active spirals.

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